LEGIBILITY NOTICE

A major purpose of the Technical Information Center is to provide the broadest dissemination possible of information contained in DOE's Research and Development Reports to business, industry, the academic community, and federal, state and local governments.

Although a small portion of this report is not reproducible, it is being made available to expedite the availability of information on the research discussed herein.

1

LA-UR--89-2876

DE89 016995

CONF-8910305--1

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36

TITLE DESIGN AND DEMONSTRATION OF HEAT PIPE COOLING FOR NASP AND EVALUATION OF HEATING METHODS AT HIGH HEATING RATES

AUTHOR(S) M. A. Merrigan, MEE-13
J. T. Sena, MEE-13

SUBMITTED TO 7th Nat'l Aero-Space Plane Technology Symp.
Cleveland, OH
October 23-27, 1989

Los Alamos

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

FORM NO. 836 R4
ST. NO. 2629 5/81

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DESIGN AND DEMONSTRATION OF HEAT PIPE COOLING FOR NASP AND EVALUATION OF HEATING METHODS AT HIGH HEATING RATES (U)

Michael A. Merrigan and J. Tom Sena
Los Alamos National Laboratory

7th National Aero-Space Plane
Technology Symposium
October 23-27, 1989

Paper Number 100

ABSTRACT

An evaluation of two heating methods for demonstration of NASP leading edge heat pipe technology was conducted. The heating methods were and RF induction heated plasma jet and direct RF induction. Tests were conducted to determine coupling from the argon plasma jet on a surface physically similar to a heat pipe. A molybdenum tipped calorimeter was fabricated and installed in an rf induction heated plasma jet for the test. The calorimetric measurements indicated a maximum power coupling of approximately 500 W/cm^2 with the rf plasma jet. The effect of change in gas composition on the heating rate was investigated using helium. An alternative to the plasma heating of a heat pipe tip, an rf concentrator was evaluated for coupling to the hemispherical tip of a heat pipe. A refractory metal heat pipe was designed, fabricated, and tested for the evaluation. The heat pipe was designed for operation at 1400 to 1900 K with power input to 1000 W/cm^2 over a hemispherical nose tip. Power input of 800 W/cm^2 was demonstrated using the rf concentrator.

INTRODUCTION

The cooling requirements for the wing and engine duct leading edges of the NASP exceed the limits of demonstrated heat pipe technology. Heating rates for these surfaces range up to 5000 W/cm^2 The external atmosphere is oxidizing and the dynamic environment severe. Design requirements call for repeated use of the aircraft without replacement or repair of the critical surfaces. If radiation heat rejection is to be used, the surfaces must operate at temperatures in the range of 1200 to 1500 K. This combination of requirements has not been encountered before and constitutes a severe heat pipe design requirement. In addition, the combination of high temperature and high heating rate complicates ground test of designs. Development of the basic heat pipe and test heat transfer technology is of fundamental interest to the NASP program.

To address the heating requirements, a series of experiments was conducted using an induction-coupled plasma torch and an rf concentrator. A refractory metal heat pipe was designed and fabricated for use in the heat source evaluation and as a demonstration of high radial heat flux operation of heat pipes.

DESCRIPTION OF HEATING METHODS

The induction plasma torch included a quartz tube, open at one end, with plasma forming gas supplied at the other end. An rf coil surrounded the tube near the center and served to couple energy into the plasma by induction. The power was supplied to the coil by a commercial rf heating unit modified to measure the operating frequency. The plasma torch operates by inductive coupling to the ionized gas at or near thermal equilibrium. Since the torch is electrodeless and can be used with any gas desired, this type of apparatus is useful in high temperature research and engineering. A plasma torch is designed to heat gases to very high temperatures by taking advantage of the high conductivity of an ionized gas.[1]

Heating by rf induction is based on three main principles: electromagnetic induction, skin effect, and heat transfer. This concept is similar to the well-known transformer theory, but modified and based on a single-turn, short-circuited secondary winding. In a conventional transformer one expects, in a simplified form, a zero flux leakage, such that the load current is related directly to the supply current by the turns ratio. The primary and secondary losses are directly related to the windings. If the secondary is considered as a single-turn, short-circuited winding, the secondary current will be high and considerable losses will develop.[2]

Applying this concept to rf heating, the heating load is a multi-turn primary and single-turn, short-circuited secondary, separated by a small air gap and a quartz insulator. Heating is affected by 'skin effects' which are a function of frequency. Current density falls off from the surface to the center of the workload with the rate of decrease higher at higher frequencies. Heating is also dependent on the resistivity and relative permeability of the material being heated. The primary is usually constructed of copper, and is generally water-cooled.

APPARATUS AND TESTING

A series of experiments was conducted with the plasma jet to evaluate instrumentation. High-temperature thermocouples were installed inside a molybdenum heat pipe shell. A black-body cavity was machined into the inside surface of the nose tip of the simulated heat pipe, and optical instrumentation was set up to read surface temperatures through the plasma jet atmosphere both axially and downward through the center of the jet and radially. These experiments indicated that black-body radiation from the plasma was at too high a level to allow reading of the surface temperatures through the gas, either axially or radially. The thermocouple instrumentation was more successful, although rf-induced voltage on the thermocouple lines was a problem, as anticipated. The most promising temperature measurement technique was provided by optical reading of the internal black-body cavity. These readings require calibration for window losses through the vacuum enclosure, but should be repeatable once calibrated.

A single pass water calorimeter was designed and built for power measurements during the high heating experiments using the plasma torch. The calorimeter had a molybdenum nose tip brazed to a stainless steel body, as shown in Fig. 1. During testing, a radiation shield was placed around the calorimeter at the spherical to cylindrical interface, to insure that the power coming from the plasma was intersected by the spherical end of the calorimeter. The lower portion of the calorimeter was insulated with carbon fiber insulation to minimize thermal exchange with its environment. Figure 2 shows the calorimeter installed in the plasma torch chamber.

The efficiency of the torch is approximately on third of the power going in the output circuit of the generator. In these tests about 17.25 kW were coupled into the gas. The opening of the torch was 20.27 cm^2 giving a heat flux through the opening of 852 W/cm^2. For an input power to the test article of 1000 W/cm^2, a total of 4.3 kW would have to be measured by the calorimeter. Experiments were conducted at different frequencies and varying gas combinations. Figure 3 shows ratio between rf generator power to the measured throughput at the calorimeter at different generator frequencies. As indicated on the graph, the lower frequency produced the higher throughput. The calorimetric measurements indicated a maximum

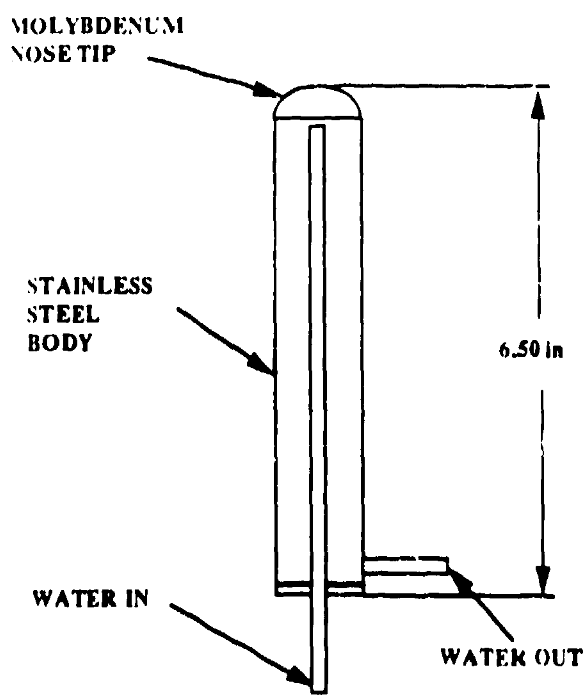

Fig. 1. Single pass water calorimeter.

Fig. 2. Calorimeter in plasma tor~h.

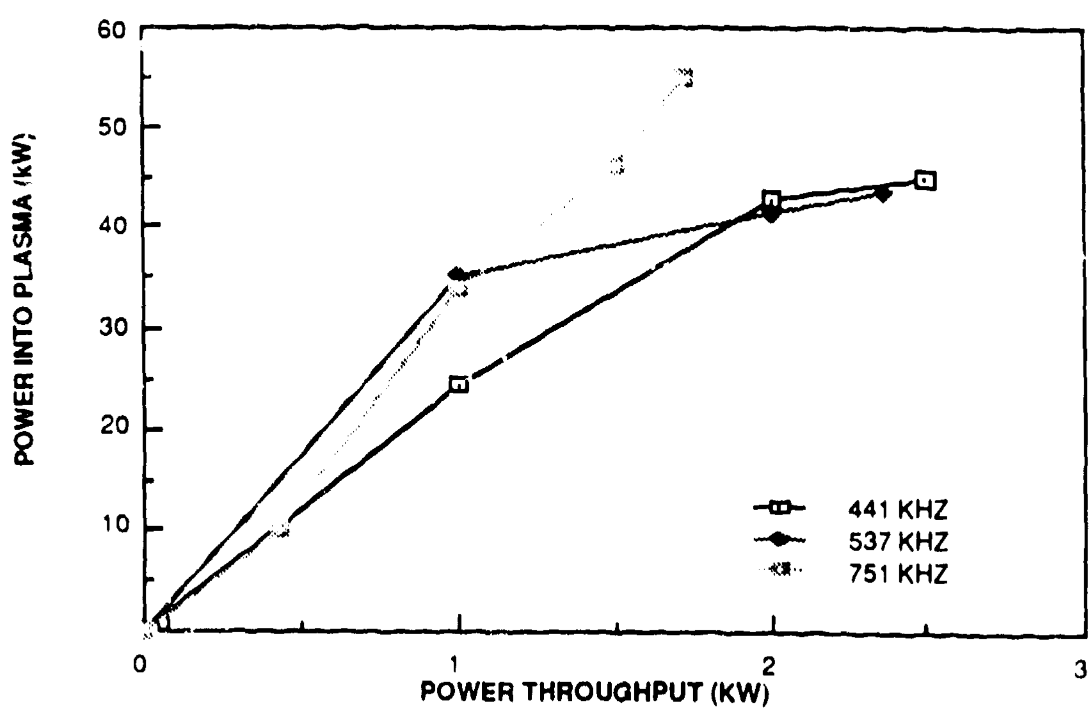

Fig. 3. Plasma power vs. power throughput.

power throughput of 2.5 kW with coupling of approximately 500 W/cm^2 at the spherical end of the calorimeter. This level was within the design range for the NASP wing leading edge heating but below design goal. The effect of change in gas composition on the heating rate was investigated using helium. Although the higher thermal conductivity of the helium might be expected to result in higher heat rates the reduced effectiveness of the rf coupling from the susceptor to the plasma resulted in a net decrease. A larger rf power source would be necessary to achieve the desired level of 1000 W/cm^2.

RF/HEAT PIPE EVALUATION

Heat Pipe Fabrication and Processing

A heat pipe was constructed from molybdenum tubing with an outside diameter of 1.90 cm, a wall thickness of 0.152 cm and a length of 50.8 cm. One layer of 150 mesh Mo screen was placed against the inner wall for circumferential fluid distribution. One layer of 40 mesh Mo screen was placed against the 150 mesh screen as a structural support to serve to deter entrainment. Each of the screen wicks was constructed by spiral wrapping screen strips over individual iron mandrels and spot welding the edge of the screen to itself to form a screen tube. Because the Mo screen was also spot welded to the iron mandrel during fabrication, the iron mandrel was dissolved with a 50/50 HCL-H_2O solution leaving behind the formed screen tubes. One end of each of the screen tubes was shaped to conform to the spherical inside tip of the heat pipe. An thermocouple well with a 0.32 cm inside diameter ran the length of the heat pipe. The heat pipe is shown in Fig. 4.

All heat pipe parts were chemically cleaned and vacuum-fired before EB welding. Before lithium charging, the heat pipe assembly was vacuum fired at 1700 K. Lithium was introduced into the heat pipe by vacuum distillation. Figure 5 is a schematic of the distillation setup attached to the heat pipe. Upon completion of the lithium distillation, the heat pipe was positioned horizontally and heated uniformly over their entire length to distribute the lithium charge and to ensure complete wetting of the interior surface.

Fig. 4. NASP heat pipe.

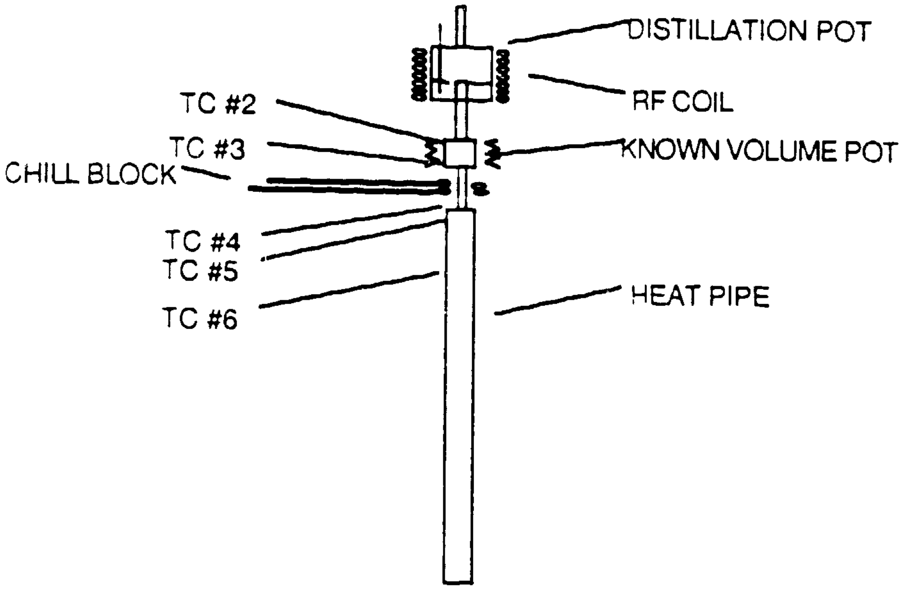

Fig. 5. Distillation setup.

Fig. 6 RF concentrator.

RF Coil

An rf concentrator was constructed of a 20.0 cm diameter by 0.157 thick copper sheet. A hole was drilled in the center of the plate to accommodate the heat pipe and an insulator. Copper tubing, 0.79 cm in outside diameter, was formed into a coil and attached to the plate at the innermost coil, thus creating a single turn transformer. A cooling coil was attached to the copper sheet on the opposite side of the rf coil. In operation voltage was induced in the copper sheet to increase coupling of the coil to the work-piece. Figure 6 is a photograph of the concentrator.

TEST ARRANGEMENT AND APPARATUS

Instrumentation

The heat pipe was instrumented with tungsten/tungsten-26% rhenium thermocouples for temperature monitoring during testing. The thermocouples were located at three location evenly spaced along the length of the heat pipe through the thermocouple well. Optical instrumentation was also used to monitor the surface temperature of the heat pipe. Because of rf-induced voltage on the thermocouples, the optical reading were more successful. The instrumented heat pipe was then inserted into a quartz vacuum envelope for testing. The rf concentrator was slid over the quartz envelope to supply heat input to the heat pipe. A photograph illustrating the setup is show in Fig .7.

Fig. 7. NASP experimental setup.

Experimental Procedure

Initially a performance test of the heat pipe was conducted to verify the start-up operation from the frozen state and to demonstrate freedom from non-condensable gas contamination. This was accomplished by setting the heat pipe vertically and heating at the bottom end to 1525 K. The test indicated that the heat pipe was free of non-condensable gas, had been loaded with sufficient lithium for operation and had a minimum amount of excess fluid during operation.

The heat pipe was tested in a vacuum test chamber with vacuum levels in the region surrounding the heat pipe in the 10^{-5} torr region. A number of orientations were investigated from a vertical position down to a 10 degree adverse tilt. These tests were conducted at different temperatures. All of the tests were started using the same reference starting condition indicated on rf generator power setting. The power setting was increased at a specified rate and temperature and power throughput recorded. This procedure was maintained until the heat pipe tip reached a temperature around 1900 K, considered a limit for the heat pipe operation.

Figures 8-13 give plots of the test data at various tilt angles of temperature vs heat input at the tip of the heat pipe in W/cm^2. As can be seen on the figures, the largest heat input occurred when the heat pipe was in a horizontal position and the lowest when in a vertical orientation.

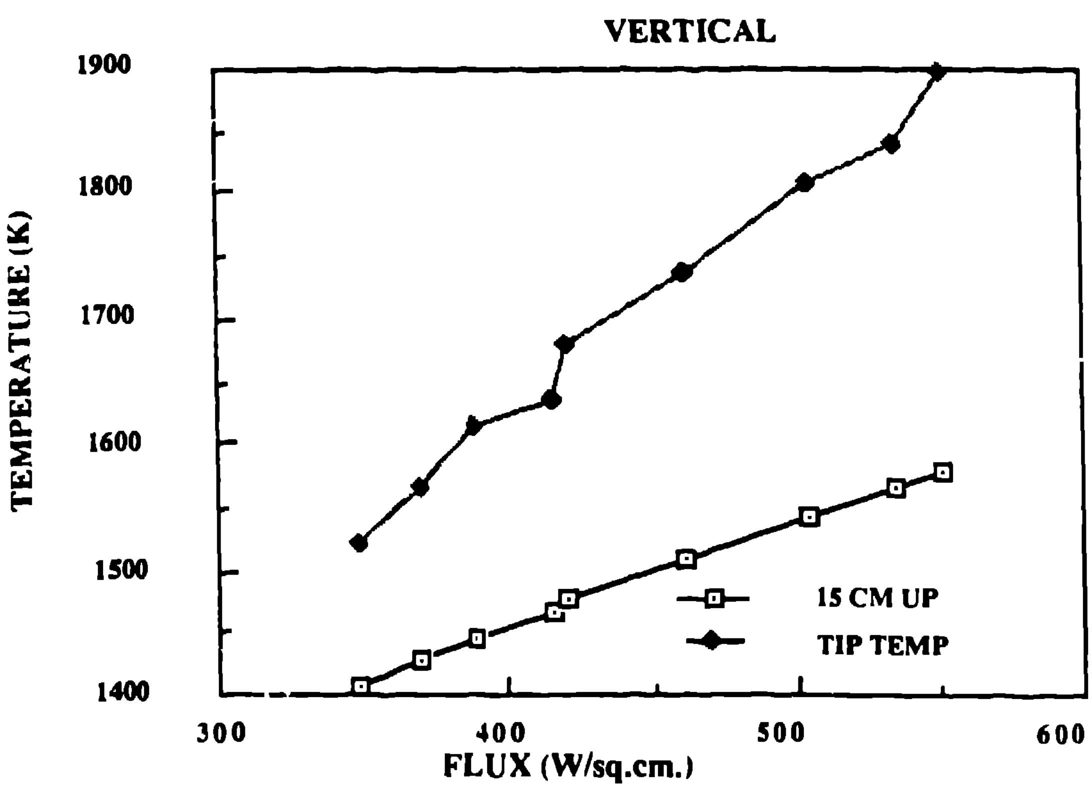

Fig. 8. Test at vertical orientation.

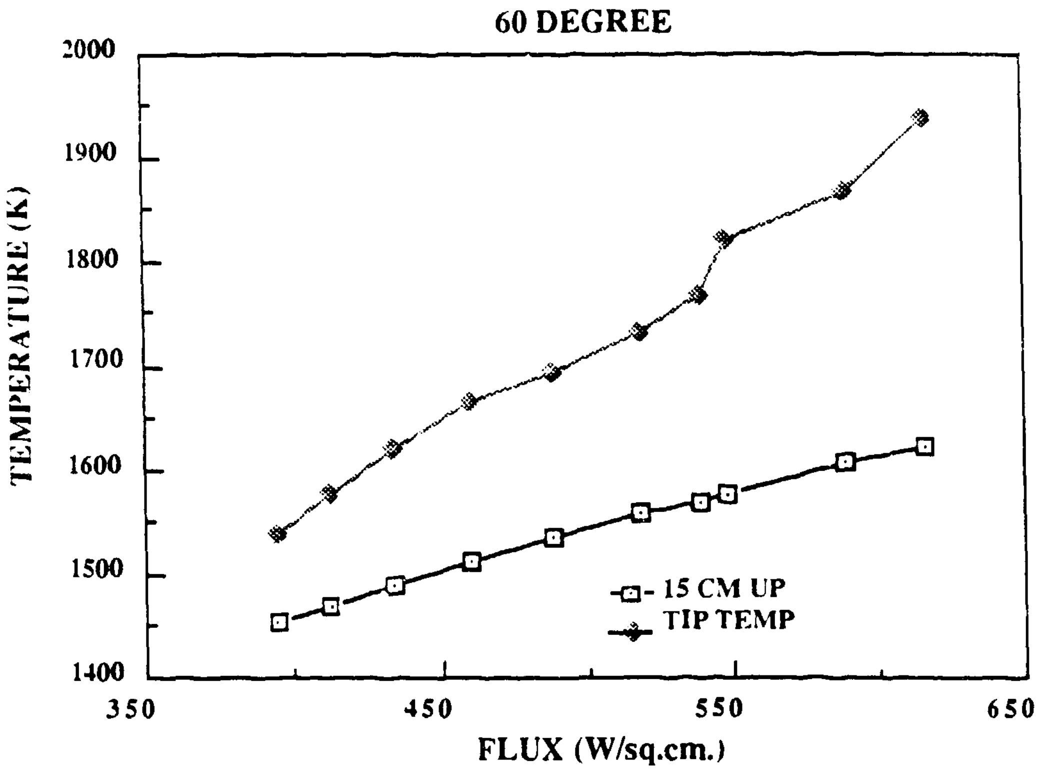

Fig.9. Test at 60 degree off horizontal.

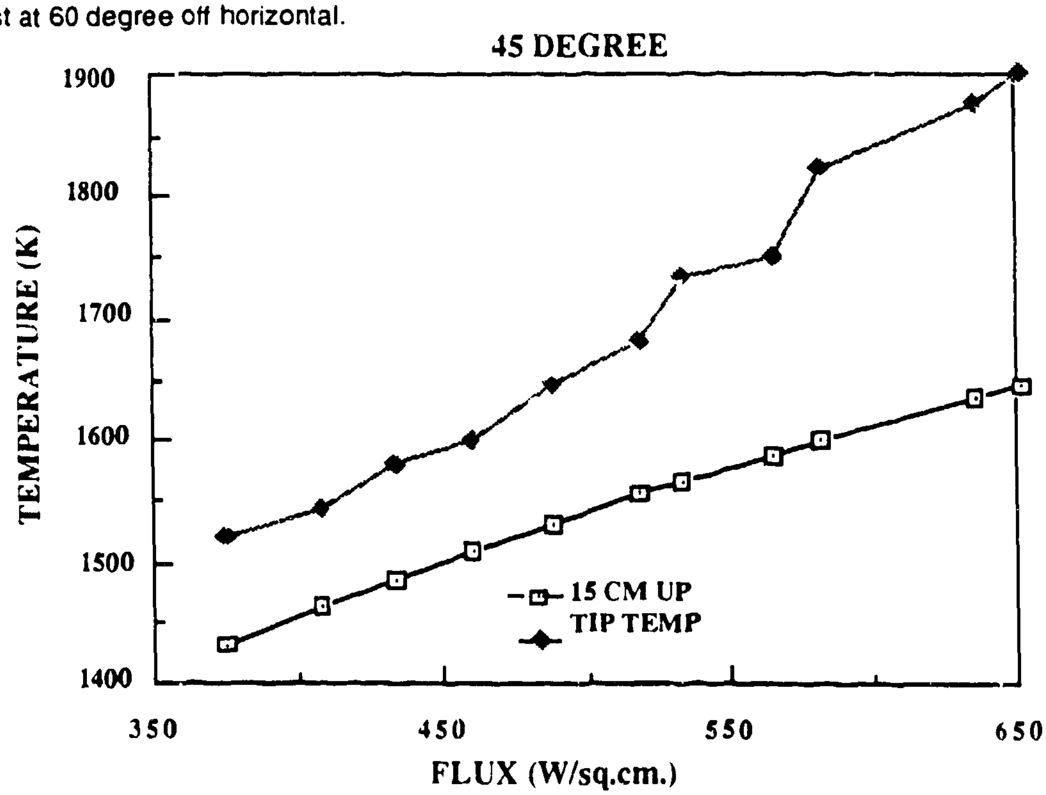

Fig. 10. Test at 45 degree off horizontal.

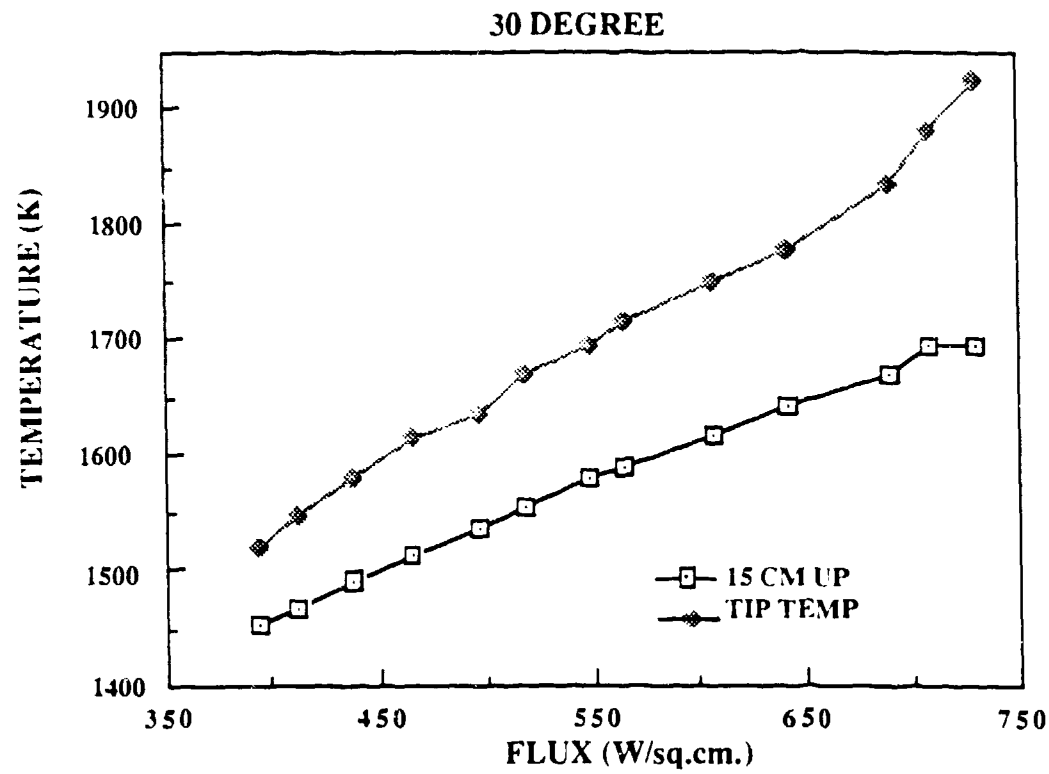

Fig. 11. Test at 30 degree off horizontal.

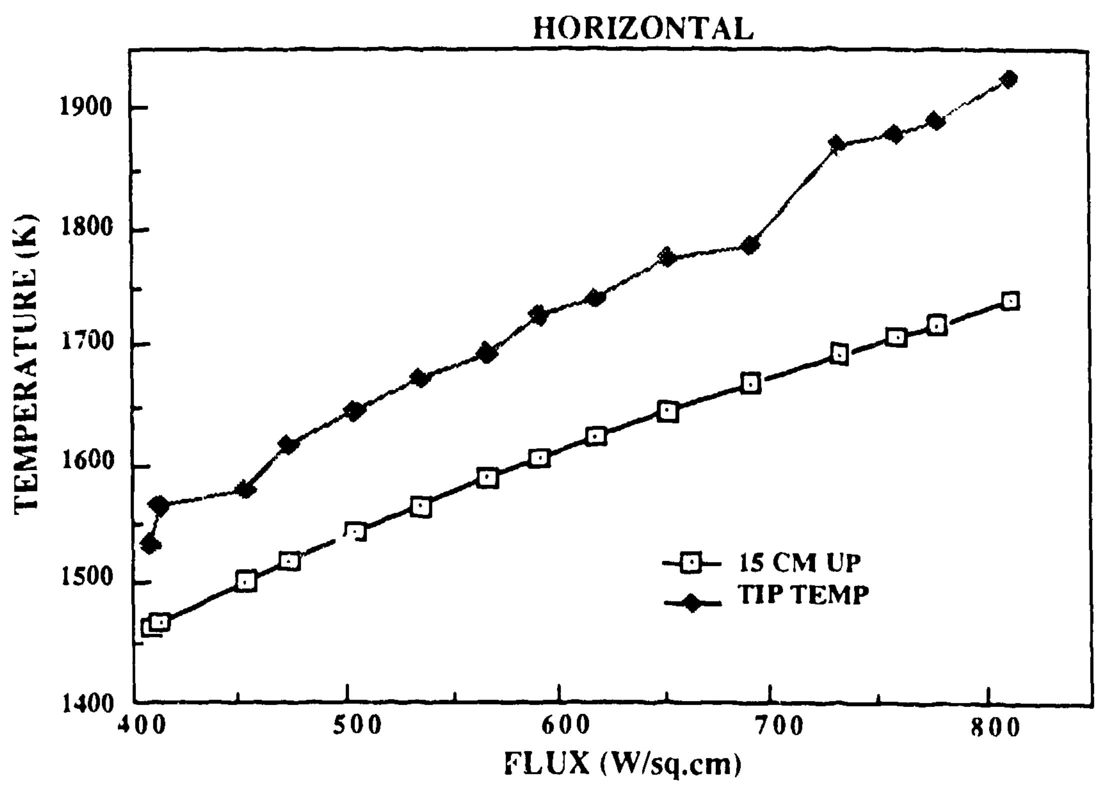

Fig. 12. Test at horizontal.

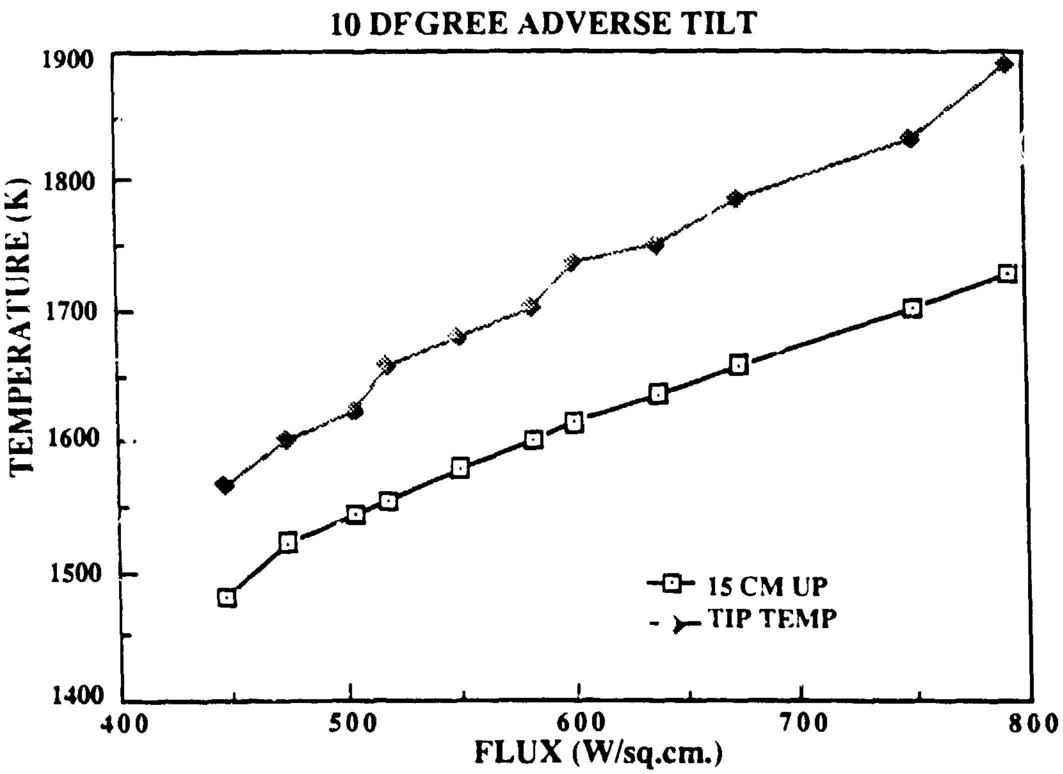

Fig. 13. Test at 10 degree adverse tilt.

CONCLUSIONS

The rf plasma jet lends itself well for heating a leading edge cooling device. The ability to couple 500 W/cm^2 is well within the design range for the NASP wing leading edge heating but below the desired goal. In order to achieve 1000 W/cm^2 using the plasma jet, a larger rf generator is required. Heating by direct rf induction was very successful. No limits on the heating ability by direct rf induction were encountered. Test results show that a refractory metal heat pipe should be seriously considered as a cooling device for NASP. Up to 800 W/cm^2 have been demonstrated using a molybdenum/lithium heat pipe. It is recommended that a larger effort be placed in evaluating refractory metal heat pipes as a means of cooling the NASP leading edge.

REFERENCES

(1) Thomas B Reed, Lincoln Laboratory, Massachusetts Institute ofTechnology, "Induction-Coupled Plasma Torch", Journal of Applied Physics (May, 1961)

(2) John Davies University of Astonin Brimingham, Peter Simpson, Ministry of Defence, "Induction Heating Handbook", McGraw-Hill Book Co. (UK) (1979)